FABRICATION OF A LOW TEMPERATURE DIFFERENTIAL STIRLING ENGINE

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DECLARATION

It is hereby declared that the project titled “LOW TEMPERATURE DIFFERENTIAL STIRLING ENGINE” is an outcome of the investigation carried out by the authors under the supervision of Dr. Md. Ehsan, Professor, BUET, Dhaka and the project or any part of it, was not submitted else where for the award of any other degree or diploma or any other publications.

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Abstract

In recent years, understanding of the stirling engine has enjoyed considerable growth. Research and development on the stirling engine has steady progressed, and many new insights, inventions, and potential applications have many discovered and explored. One of the most exciting recent developments is the so called “low temperature differential” stirling engine. This new type of stirling is capable of running on very small differences in temperature between the hot and cold sides, or better to say, between the warm and cool sides. Low temperature differential stirling engine have been built that run on differentials ranging from just under 100°C (180°F) down to an incredible 1/2°C (1°F). This means that stirling engines can now utilize low grade heat sources for their operation ranging from passive solar or geothermal energy to industrial process waste heat. Weather low temperature differential stirling engines can be put to practical use is an open question and still the subject of ongoing research and development work is being carried out worldwide at universities, government laboratories, and in private sector.

The objective of this project was to examine the history and development of Stirling Engines and through the process of examination, take the concepts and fundamental Characteristics of Stirling engines, and build a working model. The ultimate goal of this Project was to create a reproduction of James Senft’s N-92 Low Temperature Differential Stirling Engine and also built another N-92 model stirling engine with rescaling of its size and then analyze their performance, make some comparisons between two models and also fine out various difficulties of this fabrication technique.

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Chapter 1

Introduction

1.1 Stirling Engine

A Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas, the working fluid, at different temperature levels such that there is a net conversion of heat energy to mechanical work.

The engine is like a steam engine in that all of the engine's heat flows in and out through the engine wall. This is traditionally known as an external combustion engine in contrast to an internal combustion engine where the heat input is by combustion of a fuel within the body of the working fluid. Unlike the steam engine's use of water in both its liquid and gaseous phases as the working fluid, the Stirling engine encloses a fixed quantity of permanently gaseous fluid such as air or helium. As in all heat engines, the general cycle consists of compressing cool gas, heating the gas, expanding the hot gas, and finally cooling the gas before repeating the cycle.

1.2 History

The Stirling engine (or Stirling's air engine as it was known at the time) was invented and patented by Robert Stirling in 1816.It followed earlier attempts at making an air engine but was probably the first to be put to practical use when in 1818 an engine built by Stirling was employed pumping water in a quarry. The main subject of Stirling's original patent was a heat exchanger which he called an "economiser" for its enhancement of fuel economy in a variety of applications. The patent also described in detail the employment of one form of the economiser in his unique closed-cycle air engine design in which application it is now generally known as a 'regenerator'. Subsequent development by Robert Stirling and his brother James, an engineer, resulted in patents for various improved configurations of the original engine including pressurization which had by 1843 sufficiently increased power output to drive all the machinery at a Dundee iron foundry.

Though it has been disputed it is widely supposed that as well as saving fuel the inventors were motivated to create a safer alternative to the steam engines of the time,[whose boilers frequently exploded causing many injuries and fatalities The need for Stirling engines to run at very high temperatures to maximize power and efficiency exposed limitations in the materials of the day and the few engines that were built in those early years suffered unacceptably frequent failures (albeit with far less disastrous consequences than a boiler explosion) - for example, the Dundee foundry engine was replaced by a steam engine after three hot cylinder failures in four years.

1.3 Types of Stirling Engines

There are two major types of Stirling engines that are distinguished by the way they move the air between the hot and cold sides of the cylinder:

1. The two piston alpha type design has pistons in independent cylinders, and gas is driven between the hot and cold spaces.
2.The displacement type Stirling engines, known as beta and gamma types, use an insulated mechanical displacer to push the working gas between the hot and cold sides of the cylinder. The displacer is large enough to thermally insulate the hot and cold sides of the cylinder and displace a large quantity of gas. It must have enough of a gap between the displacer and the cylinder wall to allow gas to easily flow around the displacer.

1.3.1 Alpha Stirling

An alpha Stirling contains two power pistons in separate cylinders, one hot and one cold. The hot cylinder is situated inside the high temperature heat exchanger and the cold cylinder is situated inside the low temperature heat exchanger. This type of engine has a high power-to-volume ratio but has technical problems due to the usually high temperature of the hot piston and the durability of its seals. In practice, this piston usually carries a large insulating head to move the seals away from the hot zone at the expense of some additional dead space.

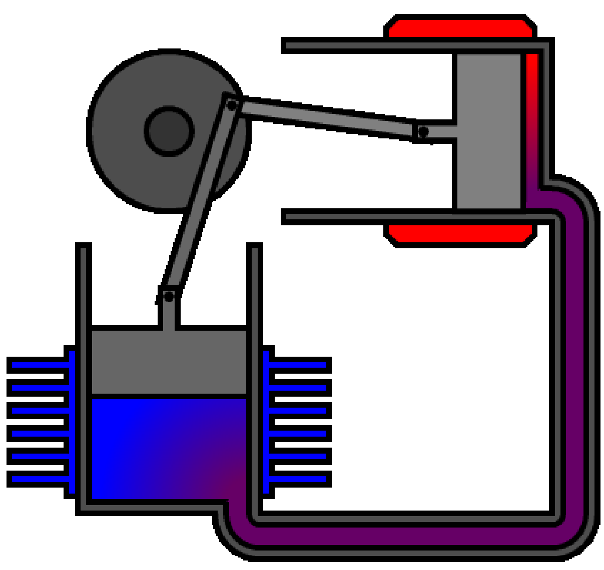

Figure 1-1: Alpha Stirling Engine

1.3.2 Beta Stirling

A beta Stirling has a single power piston arranged within the same cylinder on the same shaft as a displacer piston. The displacer piston is a loose fit and does not extract any power from the expanding gas but only serves to shuttle the working gas from the hot heat exchanger to the cold heat exchanger. When the working gas is pushed to the hot end of the cylinder it expands and pushes the power piston. When it is pushed to the cold end of the cylinder it contracts and the momentum of the machine, usually enhanced by a flywheel, pushes the power piston the other way to compress the gas. Unlike the alpha type, the beta type avoids the technical problems of hot moving seals.

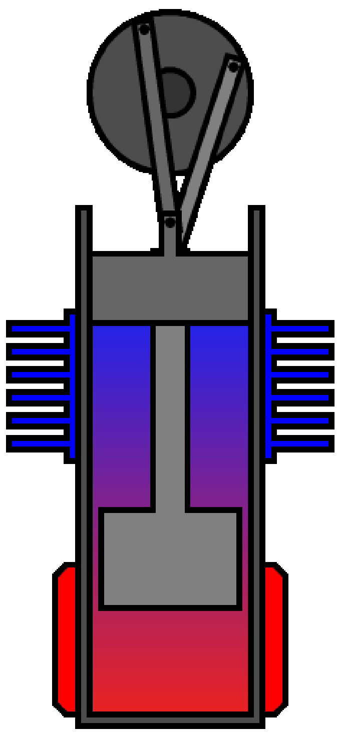

Figure 1-2: Beta Stirling Engine

1.3.3 Gamma Stirling

A gamma Stirling is simply a beta Stirling in which the power piston is mounted in a separate cylinder alongside the displacer piston cylinder, but is still connected to the same flywheel. The gas in the two cylinders can flow freely between them and remains a single body. This configuration produces a lower compression ratio but is mechanically simpler and often used in multi-cylinder Stirling engines.

1.4 The Development of Low Temperature Differential Stirling Engines

In the spring of 1983, prof. Ivo Kolin of university of Zagreb in Croatia pleasantly started the stirling engine world by publicity exhibiting an engine running on heat of boiling hot water. The setting was at a short course on stirling engines taught by Prof. Kolin, Prof. Walker, and myself at the inter university center in the historic coasts city of Dubrovnik. While Prof. Kolin described to the audience the engine that he had been developing about three years, his wife, Vlasta, devotedly poured boiling hot water into one compartment of he engine and cold water into another.

At the time, 100°C in itself was an incredibly low temperature difference for a stirling engine run on. It was all the more astonishing that the engine continued to run for a long time at lower and lower temperature differentials between the water reservoirs. Running slower and slower as the hot water cooled down and the cool water warmed up, the engine finally came to a complete stop when the temperature differential dropped below about 20°C (36°F).

Prof. Kolin's engine was built entirely with hand tools. It featured a square displacer chamber and a rubber diaphragm in place of a piston and cylinder. The Styrofoam displacer was 20 cm (7-7/8 in) square. A unique feather of this engine was a "slip link" drive for the displacer which gave it an intermittent motion; this type if motion is thermally beneficial in slow moving engines. A speed of 50 rpm was typical for his engine with a temperature difference of 50°C in its reservoirs. This first LTD engine is completely described in Ivo koflin's book isothermal stirling cycle engine which even includes fully dimensioned drawings (in metric units) so that anyone interested can make an exact replica.

In the fall of 1983 the first ringbom type of LTD Stirling engine was built at Argonne National Laboratory. This engine design it introduce a round horizontally oriented displacer chamber which could be placed over a container of hot water for the heat source. The displacer of the engine was about 8.5" in diameter and was driven by a small piston and cylinder unit to grove an intermittent motion with a phasing the varied with the engine speed. The main piston drives features a rocking lever which the freed piston of virtually all side loading for low friction and wear.

The Argonne engine proved to be a good demonstrator of stirling engine operation, with about to cups of near boiling hot water poured into the lower insulated reservoir and like amount of ice water placed on the top of the displacer chamber, the engine starts after few minutes and run about 15 minutes. When set to a low compression ratio the engine will run at a temperature difference of 7°C. The engine resides at the laboratory under the watchful care of senior scientist Dr. Paul Roach where it is favorite attraction for visitors.

From these first two engine prof. Kolin and the James R. senft work parallel over the next decayed each developing a series of LTD engine.

There are three different type of engine were introduced L-27 solar rinbom engine, P-19 ultra low temperature differential engine, N-92 NASA demonstration engine whose construction is descried in this report.

Chapter 2

Theory and Operation

2.1 The Stirling Cycle

The idealised Stirling cycle consists of four thermodynamic processes acting on the working fluid:

1.**Isothermal Expansion**. The expansion-space and associated heat exchanger are maintained at a constant high temperature, and the gas undergoes near-isothermal expansion absorbing heat from the hot source.
2.**Constant-Volume (known as isovolumetric or isochoric) heat-removal.** The gas is passed through the regenerator, where it cools transferring heat to the regenerator for use in the next cycle.
3.**Isothermal Compression.** The compression space and associated heat exchanger are maintained at a constant low temperature so the gas undergoes near-isothermal compression rejecting heat to the cold sink
4.**Constant-Volume (known as isovolumetric or isochoric) heat-addition.** The gas passes back through the regenerator where it recovers much of the heat transferred in 2 to 3, heating up on its way to the expansion space.

Theoretical thermal efficiency equals that of the hypothetical Carnot cycle - i.e. the highest efficiency attainable by any heat engine. However, though it is useful for illustrating general principles, the text book cycle it is a long way from representing what is actually going on inside a practical Stirling engine and should not be regarded as a basis for analysis. In fact it has been argued that its indiscriminate use in many standard books on engineering thermodynamics has done a disservice to the study of Stirling engines in general.

Other real-world issues reduce the efficiency of actual engines, due to limits of convective heat transfer, and viscous flow (friction). There are also practical mechanical considerations, for instance a simple kinematic linkage may be favoured over a more complex mechanism needed to replicate the idealized cycle, and limitations imposed by available materials such as non-ideal properties of the working gas, thermal conductivity, tensile strength, creep, rupture strength, and melting point.

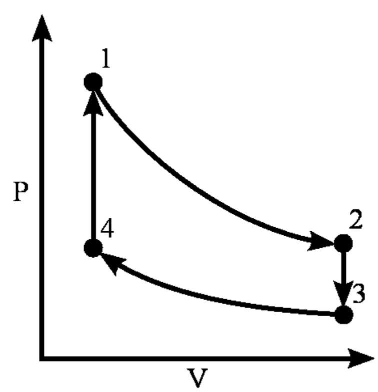

Figure 2-1: P-V diagram

2.2 The real Stirling process

While discussing the ideal Stirling process, we assumed isothermal processes. But to ensure such a process, it has to go infinitesimally slowly to always ensure equilibrium of temperature. When building an engine it is difficult to realize the isochors processes while at the same time having an evenly running system. So in every Stirling engine built, the different steps are not separated strictly but overlap each-other.

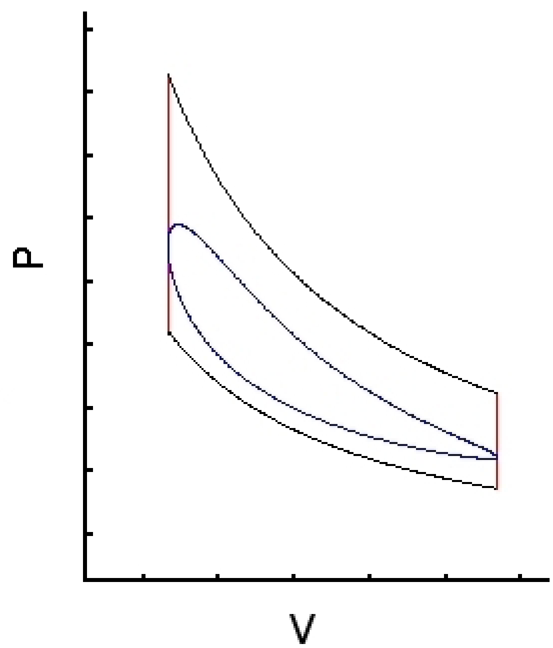

Figure 2-2: Ideal Stirling process P-V diagram

2.3 The Components of LTD Stirling Engines

The components of a LTD Stirling engine are identical in character to those of a conventional Stirling engine. The only differences are in the relative proportions of the engine parts. Figure 1 is a schematic representation of an LTD engine capable of operating at quit a low differential in temperature between the hot and the cold sections. The major components shown in the illustration are exactly those to be found in any Stirling engine of the split cylinder or gamma type.

All but one of the components in figure 1 is devices with which any one of a mechanical bend id familiar. The exception may be the item labeled as the displacer. The displacer usually takes the same from as a piston but its purpose is not to compress or expand the engine. In the illustration here it is purposely depicted as not being a close fit in its cylinder. There is sample space for air to flow around it as it is made to reciprocate within its chamber. Its function is to take up space within the chamber so that which ever way it is moved, the air goes around it to the other side. In this way it is possible to move air back and forth in side the engine chamber.

The displacer chamber has one end heated and the other cooled. Connected to the displacer section is a piston and cylinder unit, which compresses and expands the engine air in the usual way. There is a linkage between the piston, displacer and the crankshaft which phases the reciprocation of the displacer about 90° ahead of that of the piston in the direction of rotation. Every split cylinder Stirling engine has these essential components. The bell crank linkage used in figure 1 is just one example of many possible mechanisms which are suitable.

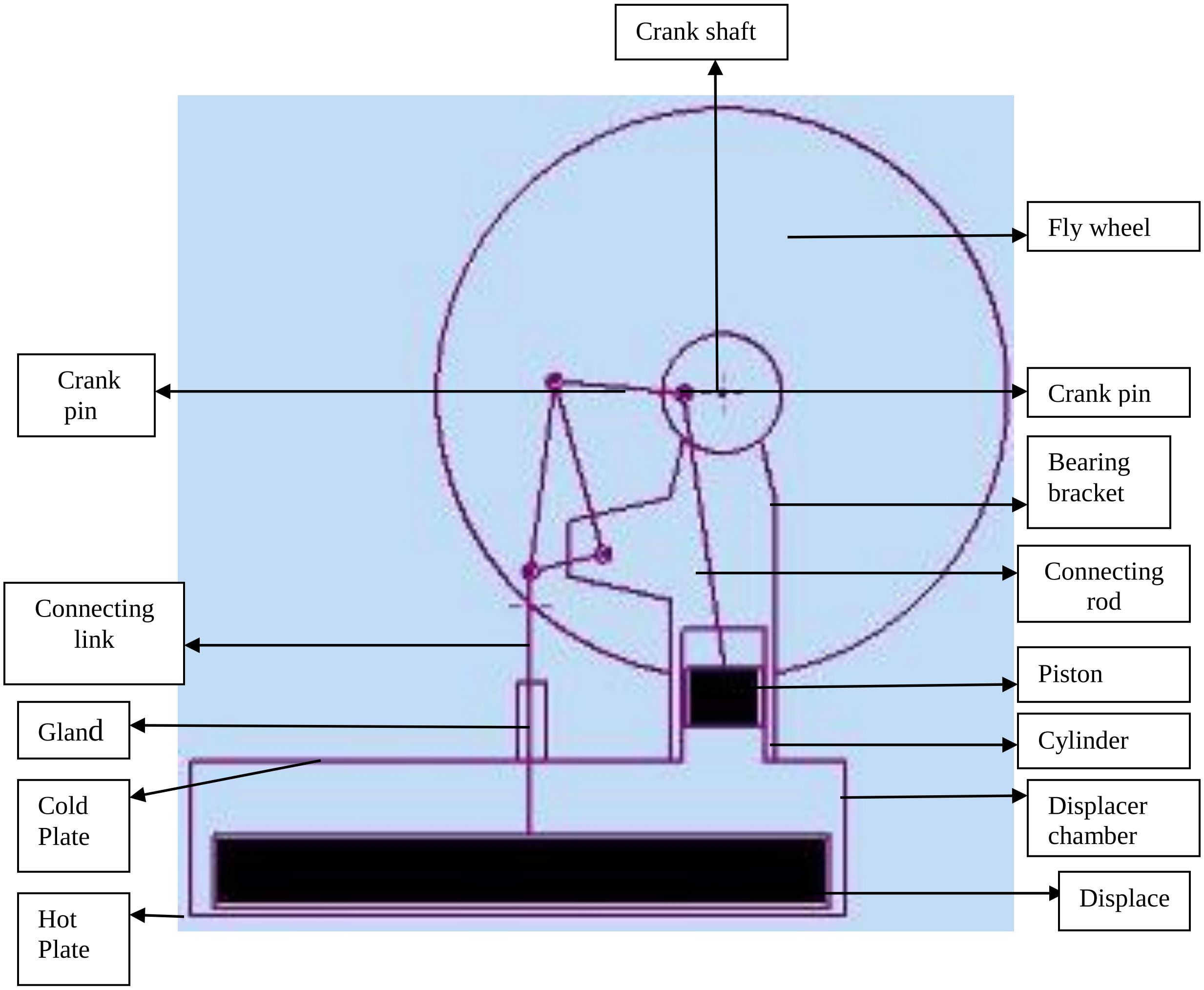

Figure 2-1: Components of Stirling Engine

2.4 How LTD Stirling Engines Work

The cycle of operation of a LTD engine is identical to that of a conventional Stirling engine. The four basic steps of the operating cycle of the engine of fig. 2-1 are depicted in figs.2-2 through 2-5. Each of the figures represents a quarter turn of the crankshaft during which a certain thermodynamic process predominately occurs within the engine. In fig.2-2 the piston is going through its reversal near its innermost dead center. During this 90°of crank rotation, normally from 45° before inner dead center to 45° after, the piston does not move very much. It goes from a little above bottom dead center down to exact bottom dead center. If you know you r trigonometry, a minute or two of calculation will show that during this whole quarter turn this piston is never farther away from bottom dead center than about 15% of its total stroke. So the volume of the air inside the engine changes very little, or is nearly constant.

Now look at what the displacer is doing during this quarter turn. The bell crank linkage, as pointed out before, puts the displacer 90° out of phase from the piston. Therefore while the piston is more or less idling around its inner dead center, the displacer is passing right through the middle of the stroke. And therefore its making its move relatively fast. The same trigonometry as before shows that in fact it travels about 70% of its full stroke during this quarter revolution of the crankshaft. Because of the clearance around this displacer, as it moves, the air in the chamber goes around it and finds itself on the other side of the engine. Thus practically all of the air that was on the cold side is moved next to the hot plate during this quarter turn. Thermal energy flows from the hot plate into the cooler air now next to it, and the air warms up.

This analysis clearly shows that during this quarter turn of crank the following thermal process occurs: without much compression or expansion, most of the air within the engine is" transferred from the cold side to the hot side, it warms up, and accordingly its pressure rises. This is one of the so-called "transfer* strokes of the Stirling engine cycle, and its main effect is simply to heat up most of the air in the engine. The mechanical energy required for the piston and displacer to move during this part of the cycle is small and comes from the rotating flywheel.

Now in Fig. 2-3 the movements of the piston and the displacer are just the opposite in character. Here the piston goes through most of its outward stroke - again about 70% of it and is pushed by the elevated pressure within the engine. This is the "expansion" stroke during which the piston delivers work to the crankshaft, and it delivers more than it took from the flywheel during the previous transfer stroke. The surplus can do work outside the engine. Meanwhile, the displacer is rounding its upper dead center and so stays near the cold plate. This keeps most of the air in the displacer chamber near the hot plate from which it continues to absorb heat as the piston carries out its expansion. Throughout the expansion stroke, the pressure steadily drops within the engine until just near the end of stroke the pressure is about equal to the outside atmospheric pressure.

During the next ninety degrees of crank rotation shown in Fig 2-4, the displacer is rapidly moving from the cold side to the hot side. This transfers the air back around the displacer to the cold side. The transferred warm air loses thermal energy to the cold plate, and drops its temperature. The pressure within the engine drops also because the volume of the engine air is virtually constant since the piston is rounding its outer dead center. Again, energy stored in the rotation flywheel carries out this "transfer" stroke too.

Since the air was just about equal to atmospheric pressure before the last transfer stroke, it ends up being below atmospheric pressure afterward. Thus during the last quarter revolution shown atmospheric pressure pushes the piston inward. Although inward stroke is called the "compression" because the piston A moves inward and decreases the volume of the engine air, it also contributes work to the engine shaft as long as the pressure inside is *below* the outside pressure. During this last part of the cycle the displacer remains close to the hot plate and the heat of compression is dissipated out through the cold plate of the engine.

2.5 The Geometry of LTD Stirling Engines

What makes a LTD Stirling engine different from a conventional flame-heated or high temperature differential engine is simply the size and shape of the displacer unit. LTD engines favor a short displacer with a large area and having a short stroke. The reasons for this come from the basic physics underlying all heat engines.

There is a definite relationship between the compression ratio of an engine and the temperatures between which it can operate. Although experiments and trial and error hinted at the qualitative character of this connection, the exact and explicit mathematical relationship was not discovered until 1985. This relationship dictates that engines operating at low temperature differentials must have low compression ratios. It is an inescapable consequence of the laws of physics governing the wonderful world we were given. Thus we know for sure now that we are not making LTD engines with low compression ratios just because the first one happened to be made that way and it worked. The fact is that it simply cannot be done any other way.

Now given that the compression ratio must be low if the temperature differential is low, this implies that the volume swept out by the displacer must be relatively large compared to that of the piston for a LTD Stirling engine. For a LTD Stirling engine to run satisfactory on the heat of a hand, its displacer must sweep out a volume about 50 times that of the piston. The displacer swept volume equals the displacer stroke times its area, and the area is proportional to the *square* of the diameter. Hence the best way to get a large volume out of reasonable size is with a large diameter and short stroke.

The additional role of the displacer in any Stirling engine is as an insulator between the hot and cold sides of the engine. The displacer must thermally isolate the hot air section from the cold section. Since heat conduction through the displacer represents a loss efficiency of the engine.

The rate of heat conduction through a solid is directly proportional to the temperature difference at each end and inversely proportional to its length. Therefore a LTD engine does not require a Long displacer to keep conduction losses down to a reasonable level. Moreover, Styrofoam is an excellent material for making displacers in LTD engines and a very short displacer made from this material will suffice. Hence short displacers are favored for LTD engines. This is also consistent with a short stroke.

The physics of heat transfer also favors a large diameter Displacer for LTD engines, in fact, the larger, the better. Consider an engine with a displacer chamber that is large enough to allow the engine to run. This means the four step cycle that was described above is being repeatedly carried out within the engine. This includes the heat flow from the hot plate to the engine air, and then later in the cycle from the engine air to the cold plate. The rate of heat transfer between the surface of the plate and the engine air next to it is directly proportional to the area of the plate and to the temperature difference between the plate and the air. If the plate were to be made larger in diarneter, the active area would be greater so the rate of heat transfer would increase. This would allow the engine to run faster than before. Therefore, from the point of view of heat transfer, the larger the plate diameter, the better. But there is an important practical consideration that prevents us from making really huge round displacers with ultra tiny strokes. This is the difficulty of keeping a large diameter displacer flat enough and squares enough to its rod to permit the displacer to come up close against the plates. The larger the displacer, the closer it must approach the plates to limit the dead space.

From the above discussion, it should be clear now why LTD engines have the shape they do, and more generally, how the geometry of any Stirling engine matches the temperature differential; that it can best work between.

2.6 The Performance of LTD Engines

As fascinating and as instructional as LTD Stirling engines are, they are not big power producers. Common sense alone dictates that an engine which runs on the warmth of a human hand cannot produce as much as an engine being heated by a blowtorch. This, and the reasons behind it, has to be realized and understood well in order to 1 design, construct, and apply LTD engines intelligently.

Slow speed operation is an intrinsic characteristic of LTD engines. To understand clearly why this is so, consider the problem of heating and cooling the air within the engine to make it perform its cycle. As already discussed, the displacer causes this to happen by moving the air back and forth between the hot and the cold sections of the engine. When cold air enters the hot section, it picks up heat from the hot engine surfaces and so rises in temperature. When the warm air is later moved back into the cooler section, it loses thermal energy to the cooler engine surfaces and drops in temperature. It is this cyclic "change in the temperature of the working air that causes its pressure to change and drives the piston to run the whole machine and do useful work".

The heat transfer between the engine surfaces and the air inside is caused by the temperature difference between them. In more precise terms, as already noted above, the rate of heat transfer is directly proportional to the difference in their temperatures. In order to get thermal energy from one to the other, one has to be hotter or warmer than the other, and the higher the difference in temperature the proportionally faster does the transfer of thermal energy take place. In conventional Stirling or hot air engines, the walls of the hot section are very hot, often red hot, and so the transfer of thermal energy to air entering the hot section is rapid. Similarly, very hot air entering the cooler section rapidly drops in temperature. That is why flames heated Stirling engines can run so surprisingly fast. Likewise, the smaller the temperature difference between the engine air and the surface of the material which it is near, the longer the heat transfer will take. This is why LTD engines tend to be low speed machines.

Also, because in a LTD engine the temperature change of the Engine air is small, the resulting pressure change over the cycle is correspondingly low. This means that the work produced over a cycle: is lower in a LTD engine than in a high temperature differential engine. Finally, the thermal efficiency of a LTD engine is inherently limited. The thermal efficiency of an engine is the work that it delivers to the piston in a cycle divided by the heat that it takes in. It is the measure of how good the engine is at converting heat into raw mechanical energy. The highest thermal efficiency that any engine cycle can have is the well-known Carnot efficiency which is the engine's temperature differential divided by its absolute upper temperature. In symbols,

$$\text{Carnot Thermal Efficiency} = \frac{TH-TC}{TH}$$

Where TH and TC are the temperatures of the hot and cold sides of [he engine expressed on an absolute scale such as the Kelvin.

The thermal efficiency of law temperature differential Stirling is very low. But for the balks engine it can always keep up the temperature differential. With boiling hot water against one plate and ice water against other side, then we get the thermal efficiency mush better.

$$\text{Thermal efficiency } \mu = \frac{TH-TC}{TH}$$

$$= \frac{(273+100)-(273+0)}{(273+100)}$$

$$= .268$$

It means that almost 27% heat is absorbed and converted into mechanical work.

Chapter 3

Fabrication of First Model

3.1 Displacer Chamber

It is the main body of the stirling engine which contains upper and lower displacer chamber plate, displacer cylinder and o ring. The upper and lower displacer chamber is made of aluminum plate. It is shaped in circular disc by machining in lathe machine. The thickness of this displacer is .5 cm. Here the displacer chamber is special type readymade fiber which outer dia is 15 cm, inner dia 14cm and length is 2.5cm. Total volume of this chamber is 385.85 cubic centimeter. The displacer cylinder has two grooves both the leading edges. The groove thickness is 0.5 cm. The two plates are joining together by seven screws.

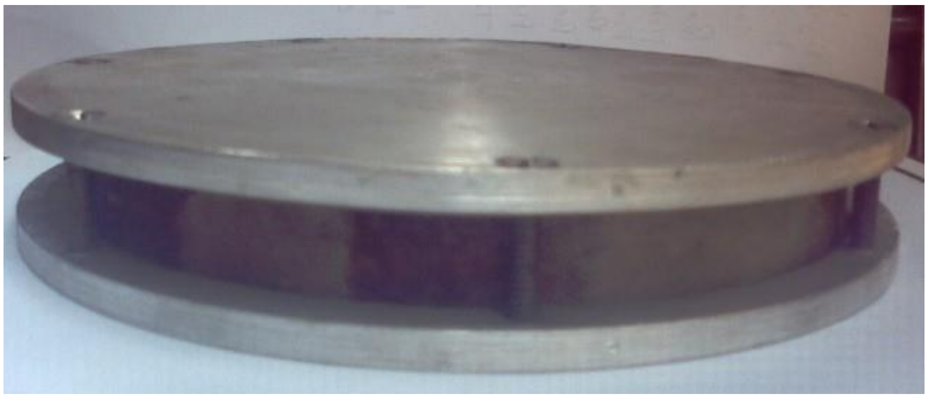

Figure 3-1: Front view of displacer chamber

Figure 3-2: Top view of displacer chamber

Figure 3-3: inside view of hat and cold plate

3.2 Displacer Piston

Here the displacer piston is made of a Styrofoam which length is .5cm and the dia is 13.5 cm. Here the volume of the piston is 71.60 cubic centimeter. In the N92 model there is regenerator used in the displacer piston. Regenerator is a device which takes heat when the heated air moves up and the temp of the air is reduced. After then when the heated air moves down then the temp take some heat and pre- heated. But here in the displacer piston we don't use any regenerator. Generally the Regenerator is a metal whish is made by coiling a wire. The displacer chamber is connected by a light weight connecting rod. There is a support in the center of the displacer chamber which holds the connecting rod.

3.3 Displacer Gland

It is situated at the top of the displacer chamber. It is made of aluminum .Fabrication technique is as similar as the fabrication technique of the power piston cylinder. Turning is done by the lathe machine and drilling is done by drill bit. The length of the gland is 2.2 cm. the base dia is 2cm and after the stepped dia is .8cm.the internal bore is .3cm.the displacer cylinder is bolted with the upper plate of the of the displacer chamber. It is a removable part.

Figure 3-4: Displacer cylinder

3.4 Power Piston and Cylinder

The power piston and cylinder is made from aluminum bar by machining in lathe. The cylinder is step turned cylinder .the base dia of the cylinder is 3.5cm and its height is .3cm after that step turning is done by reducing its dia into 2cm up to the length 3.2cm. The internal dia of the cylinder is 1.5 cm.The volume of the cylinder is 6.418 cubic centimeter.

The power piston is made of aluminum bar .The aluminum piston is made by turning the bar in lathe machine. The piston is positioned inside the cylinder with a very close clearance. The dia of the piston is 1.5 cm. and the length is 1.2cm. The volume of the power piston is 2.12 cubic centimeter. In the centre of the piston there is a hole .The dia of the hole is .5 cm .Thread is cutting inside the hole to lock the screw of the piston yolk.

Figure 3-5: top view of cylinder without piston

Figure 3-6: top view of cylinder with piston

3.5 Fly wheel Stand

It is made of aluminum .the base of the stand is joined with the top plate of the displacer chamber by two screw. It is also a removable part .the base length is 3.2cm ,thickness is .5cm and the height is 17cm.There is a hole which mount a flywheel housing. The dia of the hole is 1.8cm and the center of the hole located 1.5cm distance from the top edge. Drilling was done by drill bit.One end of the stand was bended by heating and on the bended face there are two holes so that is can attach with the top plate of the displacer chamber by the screw.

Figure 3-7: Fly wheel stand with a flywheel attachment

Figure 3-8: Front views of flywheel stand attachment

3.6 Flywheel Housing

It's made of aluminum. It is mounted on the dole of the flywheel stand. The length of the housing is 2cm.The housing contain two bearings on its two sides. The outer race of the bearing 1.5cm and the inner race is .5cm.The crank shaft length is 4cm and the dia of the crankshaft is .5cm.Here turning and drilling was performed to manufacture it.

Figure 3-9: Flywheel housing

Figure 3-10: Top view if the flywheel housing

3.7 Flywheel Hub

Fly wheel hub is made of aluminium.the dia of the flywheel hub is 2.3 cm. The length if the flywheel hub is 1cm.the bore of the flywheel is .5cm.along the length of the flywheel there is a hole where thread is cut .a screw is passed through the hole to the shaft so that it can moves with the hub at a same speed. There is an off centered pin where the connecting rod is connected.

There is another same hub to the opposite of the flywheel. Construction is same as the flywheel but it is made if bronze. Here the screw that is used to lock the shaft is also use as a counter weight. Diameter of the hub is 2.1cm and the inner dia of the hub is .5cm.

Figure 3-11: Press fitted flywheel hub situated in the power piston side

Figure 3-12: Fly wheel hub with of centering mechanism

Figure 3-13: Hub attached in flywheel

3.8 Flywheel

The fly wheel is turned from aluminum bar stock. The deep counter bore brings the flywheel mass between the two main bearings which minimizes the friction loss due to the gravity. There is a drill at the center of the flywheel .Which is 1.8 cm dia and which is closely fitted to the hub.

Figure 3-13: Flywheel before attachment

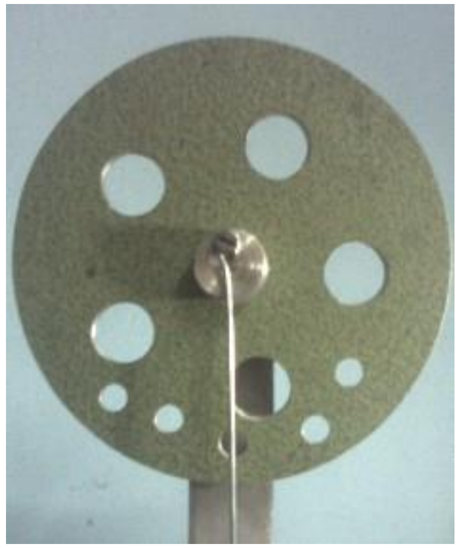

Figure 3-14: Flywheel after complete manufacturing

3.9 Connecting Rods

There are two connecting rods .They made a link between a piston and the off centering pin of the flywheel hub. According to the sliding crank mechanism piston moves up and down. The connecting rod is made of the spoke used in rickshaw. The end oh the connecting rod is bended in order to attach the rod with the off centered pin and the hole of the piston yolk. The figure of the connecting rod is given below.

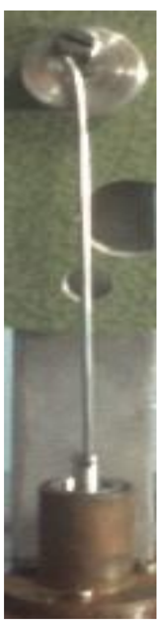

Figure 3-15: Front side connecting rod

Figure 3-16: Rear side connecting rod

3.10 Final Assembling

After manufacturing all parts individually the engine final assembly is done. First of all the two O ring put into the groove .the fly wheel stand is attached with the top plate. The piston is attached with the top plate and also the displacer piston is also attached with the top plate. Before attach the flywheel stand the flywheel housing is put into the stand hole .Bearing are attach to the two end of the housing and bearing hold the crankshaft. At the two end of the crankshaft flywheel hubs are attach .then screw the off centering pin into the two hubs and joined one end of the connecting rod. The other ends of the connecting rod are attached with the displacer piston and the power piston. Then set the displacer chamber ring in between two plates and join them by screws.

3.11 Views after Final Assembly

Figure 3-17: Front view

Figure 3-18: Rare view

Figure 3-18: side view

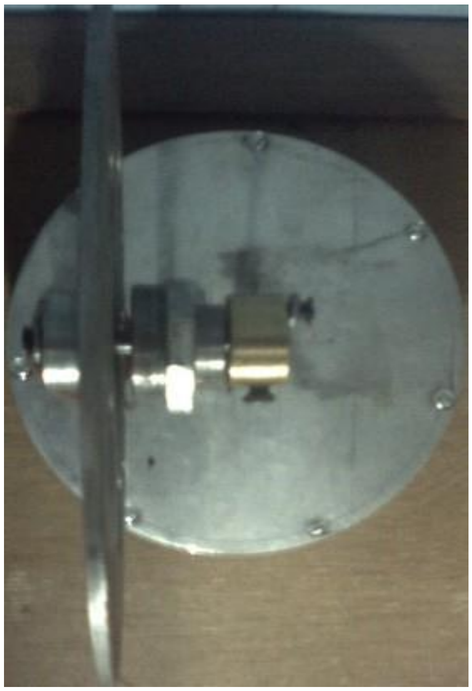

Figure 3-19: Top view

Chapter 4

Fabrication of Second Model

4.1 Displacer Chamber

It is the main body of the stirling engine which contains upper and lower displacer chamber plate, displacer cylinder and o ring. The upper and lower displacer chamber is made of aluminum plate. It is shaped in circular disc by machining in lathe machine. The thickness of this displacer is .5 cm. Here the displacer chamber is a PVC pipe which outer dia is 27.2 cm, inner dia 25.5cm and length is 3.5cm. Total volume of this chamber is 1787.468cubic centimeter. The displacer cylinder has two grooves both the leading edges. The groove thickness is 0.5 cm. The two plates are joining together by seven screws.

Figure 4.1: Displacer chamber

4.2 Displacer Piston

Here the displacer piston is made of a Styrofoam which length is .5cm and the dia is 24.5.5 cm. here the volume of the piston is 282.861 cubic centimeter. In the N92 model there is regenerator used in the displacer piston. Regenerator is a device which takes heat when the heated air moves up and the temp of the air get reduced. After then when the heated temperature moves down then the temp take some heat and pre heated. But here in the displacer piston we don’t use any regenerator. Generally the Regenerator is a metal whish is made by coiling a wire. The displacer chamber is connected by a light weight connecting rod. There is a support in the center of the displacer chamber which holds the connecting rod.

4.3 Displacer Gland

It is situated at the top of the displacer chamber. It is made of aluminum .Fabrication technique is as similar as the fabrication technique of the power piston cylinder. The length of the cylinder is 4 cm. The base dia is 3cm and after the stepped dia is1.4cm.the internal bore is .3cm.the displacer cylinder is bolted with the upper plate of the of the displacer chamber. It is a removable part.

Figure 4-2: Displacer cylinder

4.4 Power Piston and Cylinder

The power piston and cylinder are made from aluminum bar turning machining in lathe. The cylinder is step turned cylinder .the base dia of the cylinder is 5.5cm and its height is .8cm after that step turning is done by reducing its dia into 3cm up to the length 3.2cm. The internal dia of the cylinder is 2.2 cm.The volume of the cylinder is 15.205 cubic centimeter.

The power piston is made of aluminum bar .The aluminum piston is made by turning the bar in lathe machine. The piston is positioned inside the cylinder with a very close clearance. The dia of the piston is 2.2 cm. and the length is 2cm. the volume of t he power piston is 2.12 cubic centimeter. In the centre of the piston there is a whole .The dia of the hole is .5 cm .Thread is cutting inside the hole to lock the screw of the piston yolk.

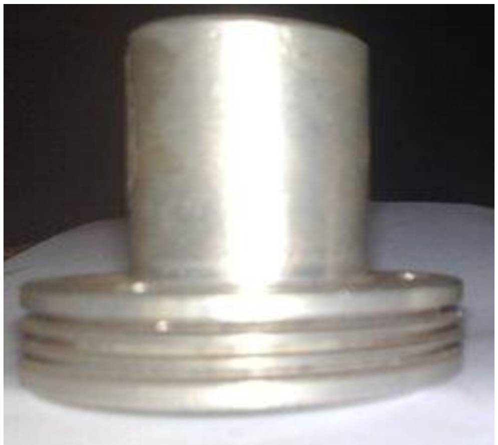

Figure 4-3: Power piston cylinder

Figure 4-4: power piston

Figure 4-4: Top view of the piston and cylinder

4.5 Fly Wheel Stand

It is made of aluminum .The base of the stand is joined with the top plate of the displacer chamber by two screw. Its is also a removable part .The base width is 4cm ,thickness is .8cm and the height is 23cm.There is a hole which mount a flywheel housing. The dia of the hole is 2.2cm and the center of the whole located 2cm distance from the top edge. Drilling was done by drill bit. One end of the stand was bended by heating and on the bended face there are two holes so that is can attach with the top plate of the displacer chamber by the screw.

Figure 4-5: Flywheel stand

4.6 Flywheel Housing

It's made of aluminum. It is mounted on the dole of the flywheel stand. The length of the housing is 4.6cm.the housing contain two bearings on its two sides. The outer race of the bearing 2.1cm and the inner race is .7cm.The crank shaft length is 8.8cm and the dia of the crankshaft is .7cm.

Figure 4-6: Flywheel housing

4.7 Flywheel Hub

Fly wheel hub is made of aluminium.The dia of the flywheel hub is 3.2 cm. The length if the flywheel hub is 1.3cm.the bore of the flywheel is .8cm.along the length of the flywheel there is a hole where thread is cut .a screw is passed through the hole to loch the shaft so that it can moves with the hub at a same speed. There is an off centered pin where the connecting rod is connected.

There is another same hub to the opposite of the flywheel. Construction is same as the flywheel hub. Here the screw that is used to lock the shaft is also use as a counter weight. Diameter of the hub is 3.2cm and the inner dia of the hub is .8cm.

Figure 4-7: Flywheel hub

Figure 4-8: separate removable parts of flywheel

4.8 Flywheel

The fly wheel is turned from aluminum bar stock. The deep counter bore brings the flywheel mass between the two main bearings which minimizes the friction loss due to the gravity .there is a drill at the center of the flywheel .Which is closely fitted to the hub.

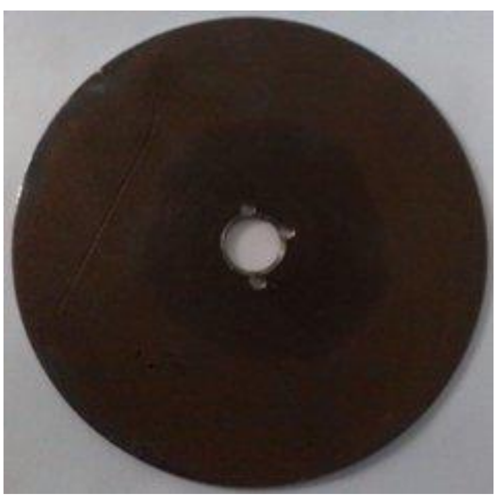

Figure 4-9: Flywheel before manufacturing

Figure 4-10: Flywheel after manufacturing

4.9 Connecting Rods

There are two connecting rods .they made a link between a piston and the off centering pin of the flywheel hub. According to the sliding crank mechanism piston moves up and down. The connecting rod is made of the spoke used in rickshaw. The end oh the connecting rod is bended in order to attach the rod with the off centered pin and the hole of the piston yolk. The figure of the connecting rod is given below.

Figure 4-11: Rear side connecting rod

Figure 4-12: Rear side connecting rod

4.10 Final assembling

After manufacturing all parts individually the engine final assembly is done. First of all the two O ring put into the groove .the fly wheel stand is attached with the top plate. The piston is attached with the top plate and also the displacer piston is also attached with the top plate. Before attach the flywheel stand the flywheel housing is put into the stand hole .bearing are attach to the two end of the housing and bearing hold the crankshaft. At the two end of the crankshaft flywheel hubs are attach .then screw the off centering pin into the two hubs and joined one end of the connecting rod. The other ends of the connecting rod are attached with the displacer piston and the power piston. Then set the displacer chamber ring in between two plates and join them by screws.

4.11 Various Views after Final Assembly

Figure 4-13: Front view

Figure 4-15: Rear view

Figure 4-16: side view

Figure 4-17: Top view

Chapter 5

Comparison and performance Analysis

5.1 Dimension Analysis

5.1.1 Model 1

Hot plate and Cold Plate

Hot plate and cold plate diameter 17 cm
Thickness of the hot plate and cold plate .5cm

Displacer Chamber

Outer diameter 15cm
Inner diameter 14cm
Length 2.5cm
The total volume is 384.85 cubic centimeter
Displacer piston dia 13.5cm
Length .5cm
Volume of displacer chamber piston 71.60cubic centimeter
Displace volume =384.85-71.96=313.25

Displacer Gland

Height 2.2 cm
Base dia 2cm
Stepped dia .8cm
Bore .3cm
Displacer piston connecting rod length 12cm
Power piston connecting rod length 11.5cm

Flywheel Hub

Dia of the hub 2.3cm
Length of the hub 1cm

Rear end flywheel dia
Dia 2.1cm
Bore .5cm
Crank shaft length 4cm

Fly Wheel

Diameter 15 cm
Thickness .3 cm
Center hole for housing 1.8cm

Power Piston and Cylinder

Outer dia of the cylinder 2cm
Inner dia of the cylinder 1.5cm
Length 3.5cm
The volume of the cylinder 6.481 cubic centimeter
Power piston dia 1.5cm
Length of piston 1.2 cm
Volume of piston 2.12cubic centimeter
Displace volume =6.418-2.12=4.316

Fly Wheel Housing

Length 2cm
Inner dia inner bore .5cm
Flywheel stand
Length 17 cm
Stand hole 1.8cm
The ratio of displacer chamber displace volume to power piston displace volume
=313.25/4.316
=72.75

5.1.2 Model 2

Hot Plate and Cold plate

Hot plate and cold plate diameter 28.5 cm
Thickness of the hot plate and cold plate .5cm

Displacer Chamber

Outer diameter 27.2cm
Inner diameter 25.5cm
Length 3.5cm
O ring .5cm
The total volume is 1787.468 cubic centimeter
Displacer piston dia 24.5cm
Length .6cm
Volume of displacer chamber piston 282.861cubic centimeter
Displace volume =1787.468-282.861=1504.607

Displacer Gland

Height 4 cm
Base dia 3cm
Stepped dia 1.4cm
Bore .3cm
Displacer piston connecting rod length 14.5cm
Power piston connecting rod length 16.5cm

Flywheel Hub

Dia of the hub 3.2cm
Length of the hub .8cm
Rear end flywheel dia
Dia 3.2cm
Bore .8cm
Crank shaft length 8.8cm

Fly Wheel

Diameter 15 cm
Thickness .3 cm
Center hole for housing 1.8cm

Power Piston and Cylinder

Outer dia of the cylinder 3cm
Inner dia of the cylinder 2.2cm
Length 4cm
The volume of the cylinder 15.205 cubic centimeter
Power piston dia 2.2cm
Length of piston 2 cm
Volume of piston 7.60cubic centimeter
Displace volume =15.205-7.60=7.605

Fly Wheel Housing

Length 4.6cm
Inner dia inner bore .7cm
Flywheel stand
Length 23 cm
Width 5cm
Thickness .8cm
Stand whole 1.8cm
The ratio of displacer chamber displace volume to power piston displace volume =1504.607/7.605=197.84

5.2 Picture Wise Relative Comparison

Fig: Front view

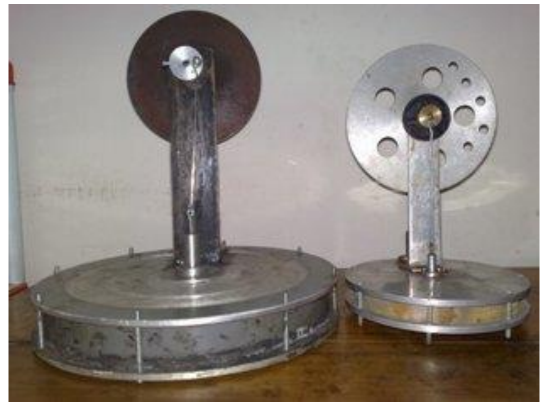

Fig: Rare view

Fig: side view

Fig: Top view

5.3 Comparative Dimensions

Model 1	Model 2
Hot plate and Cold Plate	**Hot Plate and Cold plate**
Hot plate and cold plate diameter 17 cm Thickness of the hot plate and cold plate .5cm	Hot plate and cold plate diameter 28.5 cm Thickness of the hot plate and cold plate .5cm
Displacer Chamber	**Displacer Chamber**
Outer diameter 15cm Inner diameter 14cm Length 2.5cm The total volume is 384.85 cubic centimeter Displacer piston dia 13.5cm Length .5cm Volume of displacer chamber piston 71.60cubic centimeter Displace volume =384.85-71.96=313.25	Outer diameter 27.2cm Inner diameter 25.5cm Length 3.5cm O ring .5cm The total volume is 1787.468 cubic centimeter Displacer piston dia 24.5cm Length .6cm Volume of displacer chamber piston 282.861cubic centimeter Displace volume =1787.468-282.861=1504.607
Displacer Gland	**Displacer Gland**
Height 2.2 cm Base dia 2cm Stepped dia .8cm Bore .3cm Displacer piston connecting rod length 12cm Power piston connecting rod length 11.5cm	Height 4 cm Base dia 3cm Stepped dia 1.4cm Bore .3cm Displacer piston connecting rod length 14.5cm Power piston connecting rod length 16.5cm
Flywheel Hub	**Flywheel Hub**
Dia of the hub 2.3cm Length of the hub 1cm Rear end flywheel dia Dia 2.1cm Bore .5cm Crank shaft length 4cm	Dia of the hub 3.2cm Length of the hub .8cm Rear end flywheel dia Dia 3.2cm Bore .8cm Crank shaft length 8.8cm
Fly Wheel	**Fly Wheel**
Diameter 15 cm Thickness .3 cm Center hole for housing 1.8cm	Diameter 15 cm Thickness .3 cm Center hole for housing 1.8cm

Power Piston and Cylinder Outer dia of the cylinder 2cm Inner dia of the cylinder 1.5cm Length 3.5cm The volume of the cylinder 6.481 cubic centimeter Power piston dia 1.5cm Length of piston 1.2 cm Volume of piston 2.12cubic centimeter Displace volume =6.418-2.12=4.316 **Fly Wheel Housing** Length 2cm Inner dia inner bore .5cm Flywheel stand Length 17 cm Stand hole 1.8cm The ratio of displacer chamber displace volume to power piston displace volume =313.25/4.316 =72.75	**Power Piston and Cylinder** Outer dia of the cylinder 3cm Inner dia of the cylinder 2.2cm Length 4cm The volume of the cylinder 15.205 cubic centimeter Power piston dia 2.2cm Length of piston 2 cm Volume of piston 7.60cubic centimeter Displace volume =15.205-7.60=7.605 **Fly Wheel Housing** Length 4.6cm Inner dia inner bore .7cm Flywheel stand Length 23 cm Width 5cm Thickness .8cm Stand whole 1.8cm The ratio of displacer chamber displace volume to power piston displace volume =1504.607/7.605=197.84

5.4 Performance Test of First Model

5.4.1 Performance Data without Load

Observation no	Temperature of hot plate(°c)	Temperature of cold plate (°c)	Temperature difference (°c)	R.P.M
1.	80	7	73	69
2.	84	7	77	74
3.	89	7	82	87
4.	93	7	86	94
5.	98	7	91	107

5.4.2 Performance Data with Load

Observation no	Temperature of hot plate(°c)	Temperature of cold plate (°c)	Temperature difference (°c)	R.P.M
1.	78	7	71	61
2.	86	7	79	63
3.	91	7	86	67
4.	94	7	87	71
5.	98	7	91	74

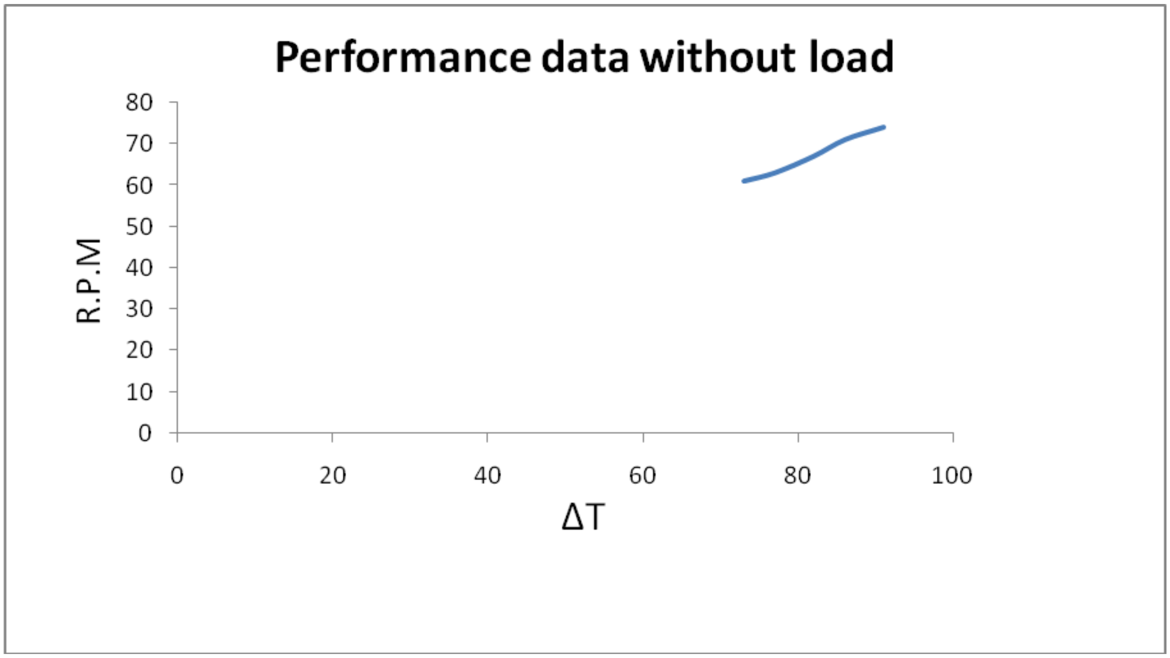

Figure 5-1: Temperature difference Vs r.p.m curve at constant top plate temperature

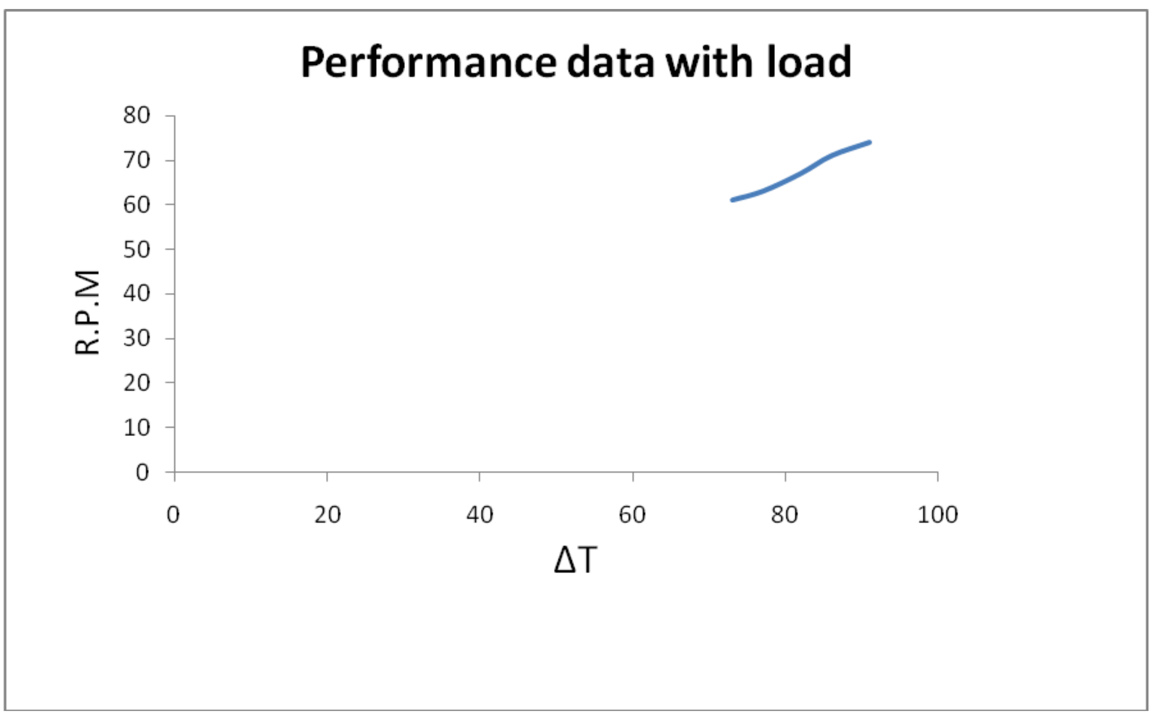

Figure 5-2: Temperature difference Vs r.p.m curve at constant top plate temperature

5.5 Thermal Efficiency Analysis

5.5.1 Performance Data without Load

Observation no	Temperature of hot plate(°c)	Temperature of cold plate (°c)	Temperature difference (°c)	Thermal Efficiency %
1.	80	7	73	20.68
2.	84	7	77	21.56
3.	89	7	82	22.65
4.	93	7	86	23.49
5.	98	7	91	24.52

5.5.2 Performance Data without Load

Observation no	Temperature of hot plate(°c)	Temperature of cold plate (°c)	Temperature difference (°c)	Thermal Efficiency %
1.	78	7	71	20.23
2.	86	7	79	22.00
3.	91	7	86	23.63
4.	94	7	87	23.80
5.	98	7	91	24.52

5.6 Speed Vs Efficiency Analysis

5.6.1 without Load

Temperature difference (°c)	Efficiency %	R.P.M
73	20.68	61
77	21.56	63
82	22.65	67
86	23.49	71
91	24.52	74

5.6.2 with Load

Temperature difference (°c)	Efficiency %	R.P.M
71	20.23	61
79	22.00	63
86	23.63	67
87	23.80	71
91	24.52	74

Chapter 6

Problems Recognition and solutions

6.1 Problems

The 1st engine was fabricated over the first semester of 2009 and the 1st engine was fabricated over the second semester of 2009. All of the Parts were made to specification as called for on the prints. One by one, slowly, each part was made. One or two parts of the engine would be made over a week of time. In doing so, the engine parts were never fitted together. The parts were not tried together until most of the parts were completed. This created many problems when trying to assemble the engine. A few parts had to be remanufactured to different tolerances so the engine could rotate. The general idea was that once all of the parts were assembled, the engine should operate without further hold up. That thinking could not be further from the truth. The engine would not rotate under any condition. After much thought and analyzing, two major problems were found to be the cause.

The first problem was that the stroke length on the displacer was much too long. The displacer would touch the top plate when going though the cycle. The displacer must come close to the plate, but never rest on the plate. By doing so, there would not be enough room for air to expand between the plate and the displacer. This was easily corrected by changing a hole on the end of the crankshaft. The hole was moved towards the center of the crankshaft about .025-inch, therefore reducing the stroke length by about .05-inch. This was all the space that was needed to allow for airflow over the top of the displacer.

The second problem was more severe. There was a definite air leak somewhere in the engine. The O-rings had been placed in proper places above the top plate. This left only one place where air leakage could occur. Air was escaping rapidly around the displacer chamber ring and the top and bottom plates. The flatness of the ring was not good enough by itself to provide a tight seal. Even tightening the nylon screws down evenly around the outside of the chamber ring did not work. This left one alternative: a Silicone seal had to be used to properly seal the gap. A bead of fish tank silicone adhesive was placed on the top and the bottom of the displacer chamber ring. The Silicone filled in small gaps with ease, creating an airtight seal. The air inside the Chamber was now completely isolated from the air outside the engine.

After fixing these two major issues, the engine now had compression. When rolled though the cycles, a definite pressure could be felt in key positions throughout the rotation.

6.2 Probable Reasons for not attaining the Expected Result of Second Model

The first model of stirling engine run successfully. The second model was completely manufactured. But it was not successfully run. There were some reasons behind this.
We designed the second model just rescaling the sizes of the first model. After completing the manufacturing it was seen that the ratio of the displacer piston displace volume to the power piston displace volume is 197.84:1. But for the first model it was 72.57:1. After manufacturing it was found that, there must have a reasonable ration between the displacer pistons to the power piston displace volume ratio. We think that these may be the major reason for not attaining the successful result of second model. More over the flywheel weight was one of the major issues for the successful running if the engine. Flywheel for the engine was selected randomly. So that it was completely unknown to us which one is suitable for the engine. So we changed it several times which was very time consuming. After that an improvement is done by manufacturing a replaceable flywheel hub attachment.

Leakage was another cause for the failure. But here we resolve for the manufacturing of model 2 quite better.

The PVC pipe which was used as a displacer chamber cylinder is over heighted. For that the displace volume in the displacer chamber is very higher than the ideal volume. These may be one of the reasons.

6.3 How to overcome problems

Because of time limitations it was not possible for us to resolve some problems. But we find out these problems. In order to run this existing model we think that we have to increase the volume of the power piston so that its displaced volume will increase. Not only is that it must to keep the displaced volume ratio near about 72.5:1 as like as the 1st model. And choose the flywheel very carefully. Proper stroke adjustment is also necessary. This model requires decreasing the height of the displacer cylinder chamber. Finally the proper sealing must be insured.

Chapter 7

Conclusions and Recommendations

Conclusions

- The first model was fabricated completely as per design and it run successfully.
- It was fabricated in a local workshop and very simple technique was used to fabricate it.
- There were slide variations in the construction of first model than the James Senft's recommended N-92 model.
- The first model performed as expected. The temperature difference was smaller than the conventional Stirling engine.
- Performance test was done and seen that, there were significant changes of r.p.m with the changing of temperature difference.
- After fabrication of first model resize attempt was taken and we fabricated another engine completely.
- Some modification was done in this second model. By specially making a provision of replaceable flywheel attachment with hub.
- But the resized model was not performed as we expected.
- There were some problems in parameters matching. Specially the ratio of the displace volume of displacer chamber to the displace volume of power piston cylinder.

Recommendations

- Some modifications should be done in order to run our second model more efficiently.
- The height of the displacer chamber should be decreased.
- Sealing should be made properly.
- The weight of the fly wheel should be reduced.
- The stroke length should be readjusted.
- Regenerator should be used in order to increase the efficiency of the engine.

Appendix

3D Parts Drawing

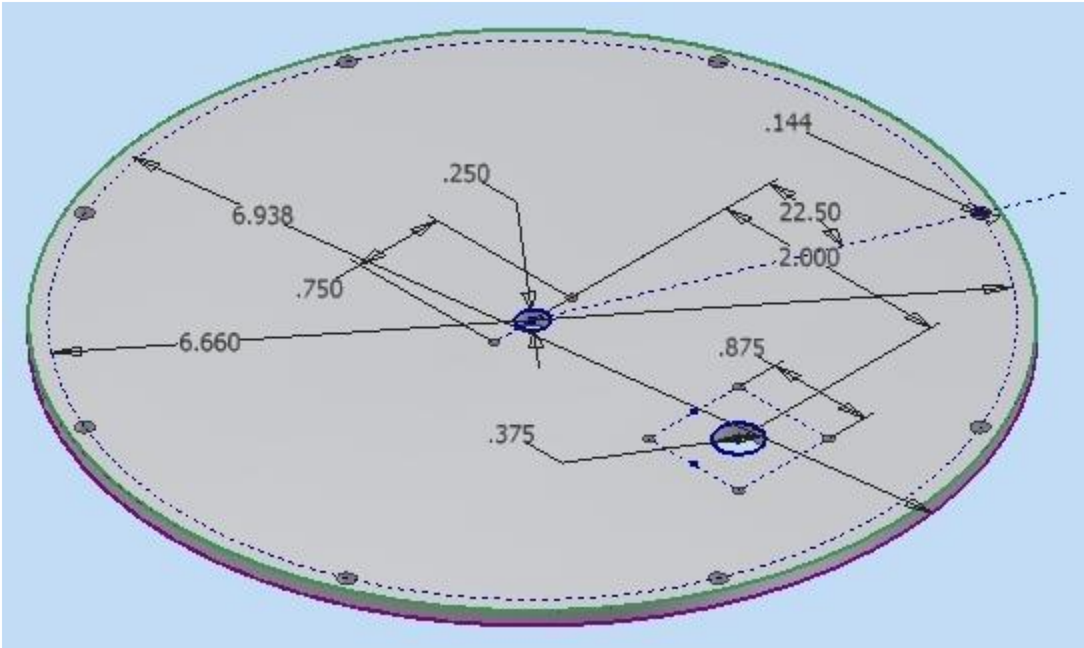

Figure A-1: Top plate

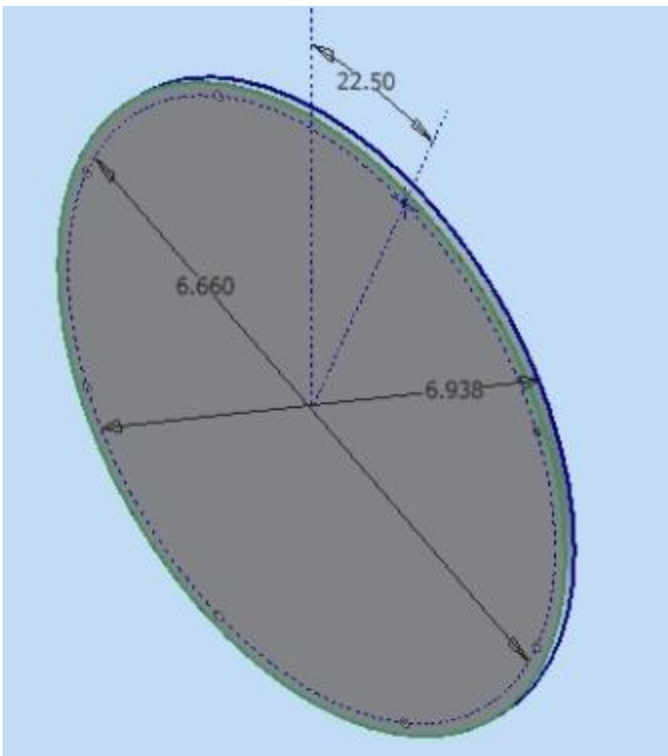

Figure A-2: Bottom plate

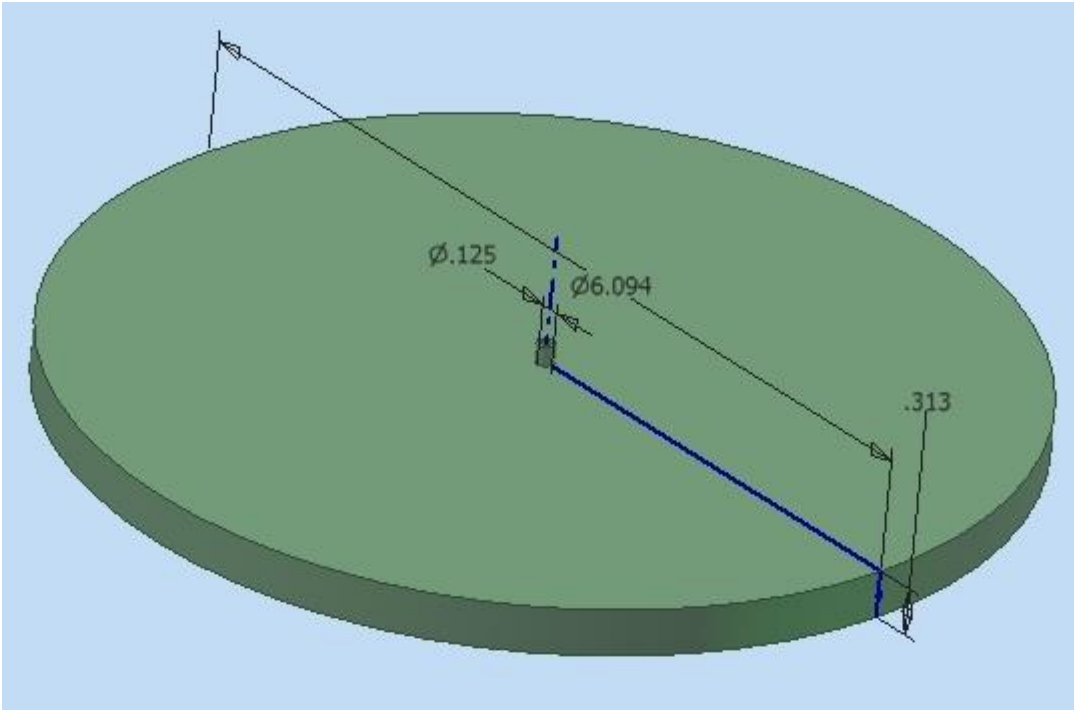

Figure A-3: Displacer piston

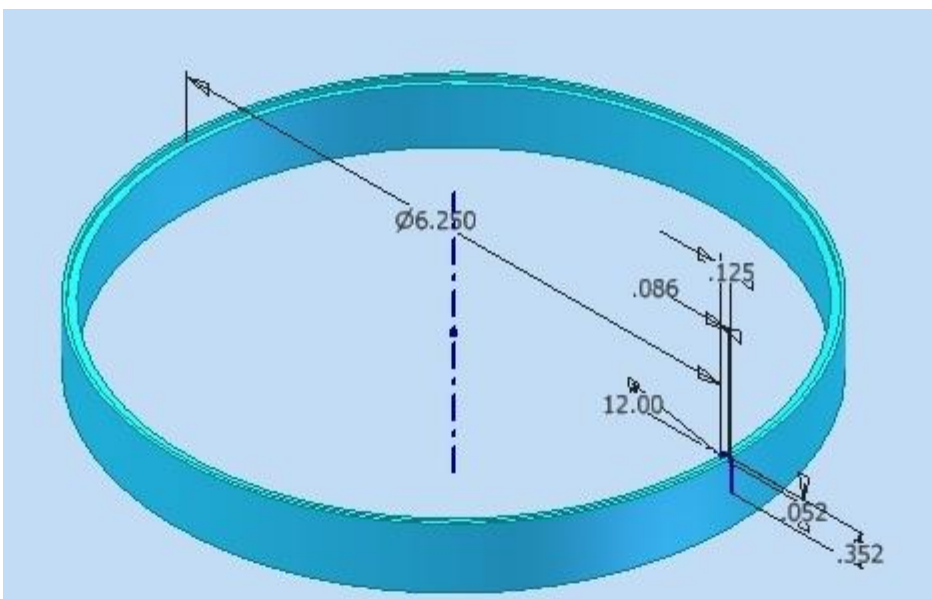

Figure A-4: Chamber Ring

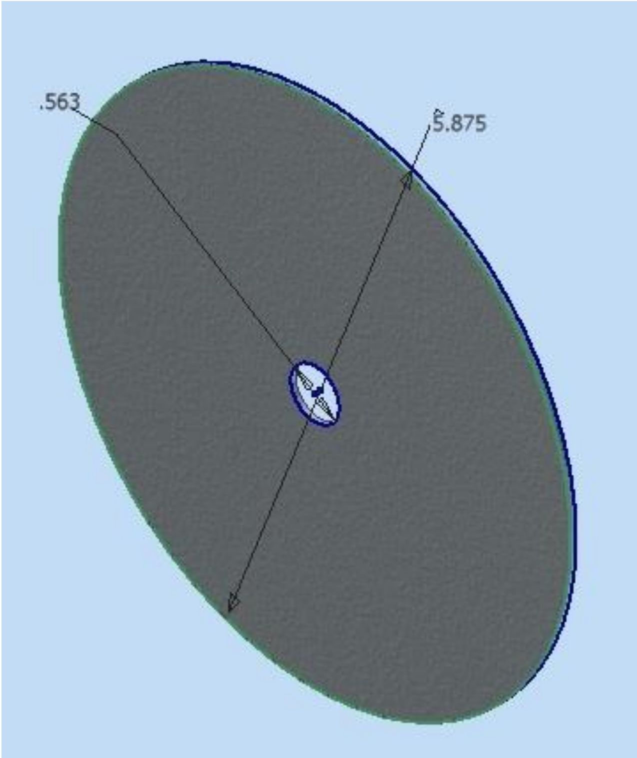

Figure A-5: Flywheel

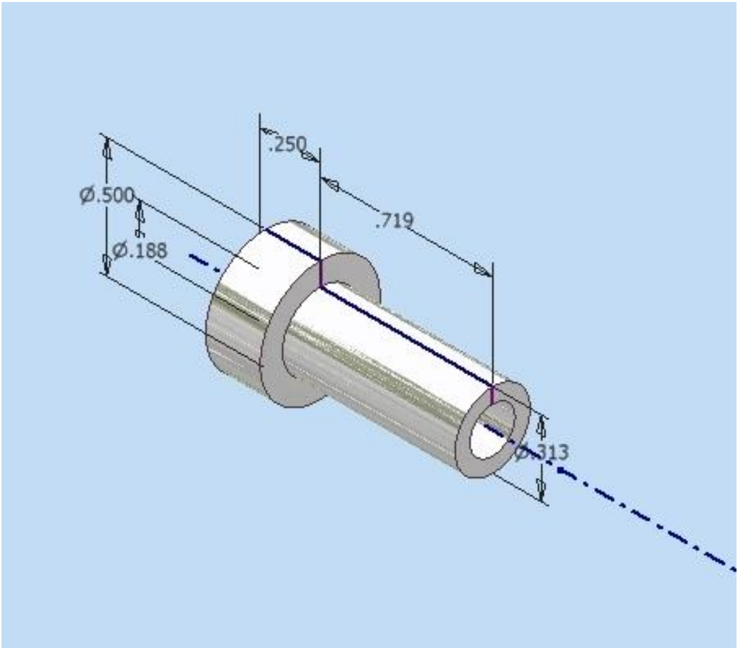

Figure A-6: Flywheel Housing

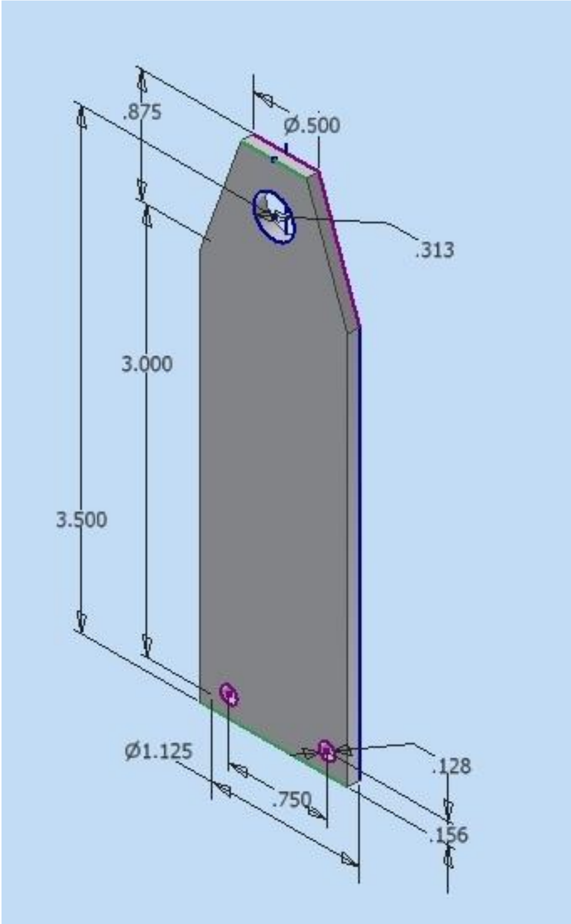

Figure A-7: Flywheel Stand

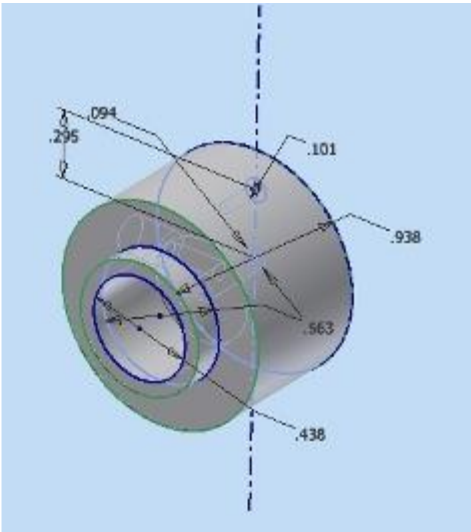

Figure A-8: Flywheel Hub

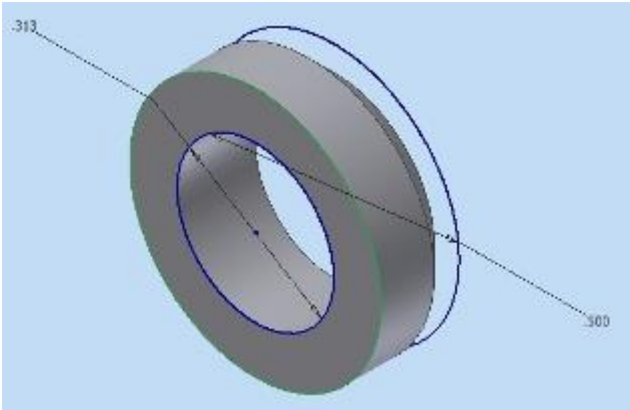

Figure A-9: Bearing Collar

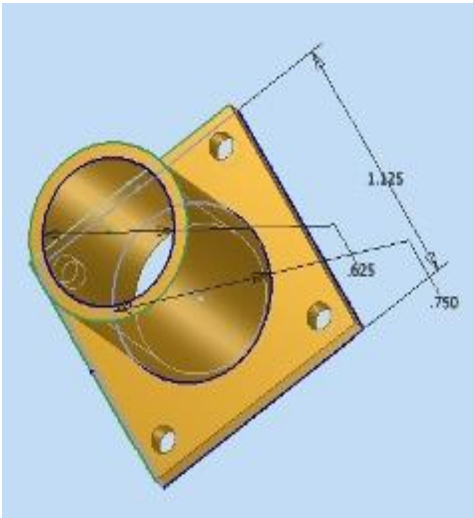

Figure A-10: Cylinder

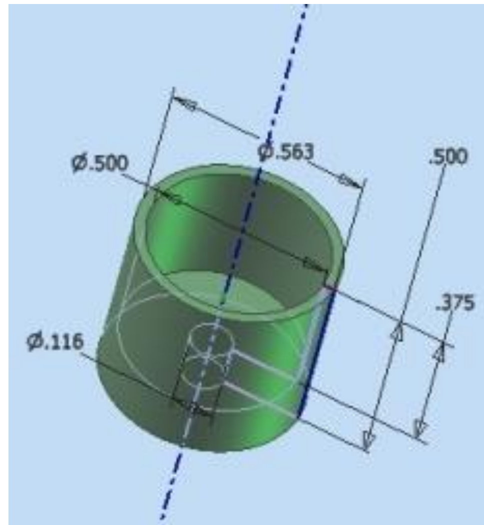

Figure A-11: Piston

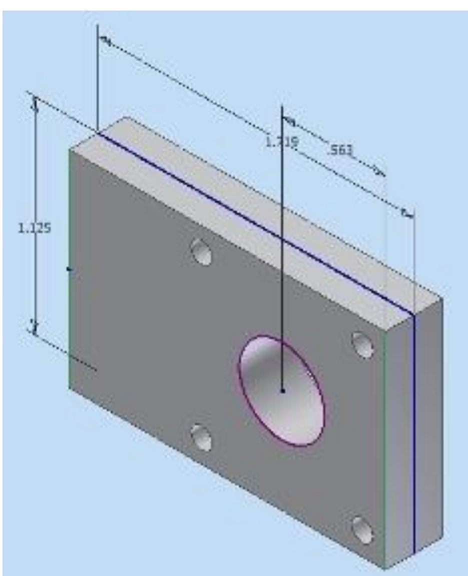

Figure A-12: Cylinder Base

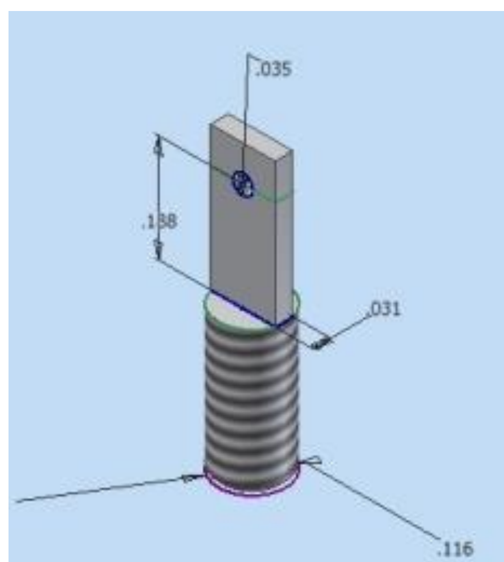

Figure A-13: Piston Yolk

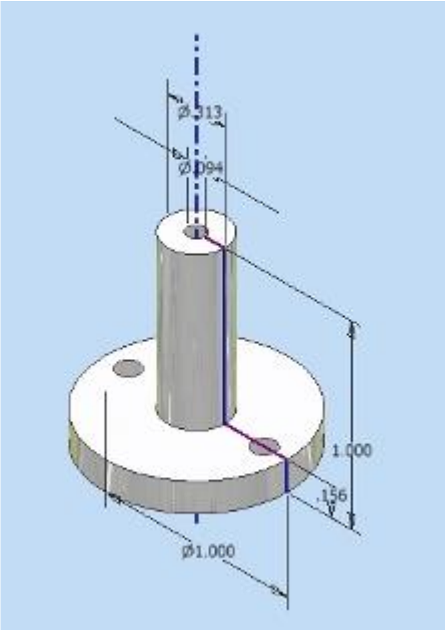

Figure A-14: Displacer Gland

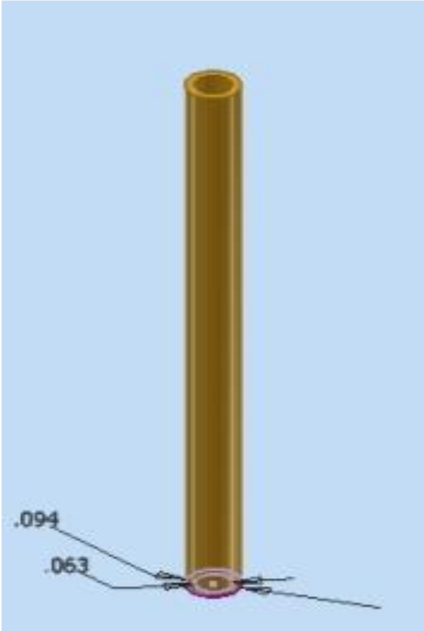

Figure A-15: Gland Rod

Figure A-16: Crank Shaft

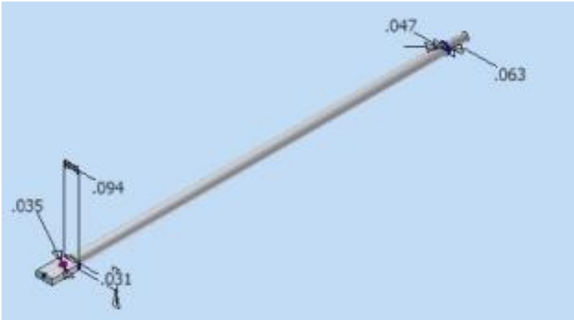

Figure A-17: Displacer Rod

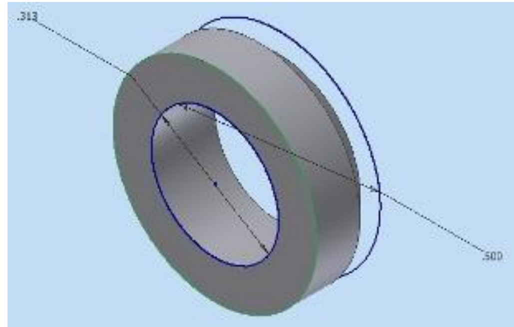

Figure A-18: Bearing Collar

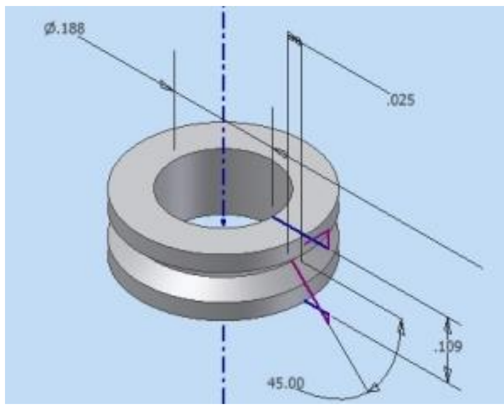

Figure A-19: Bearing Ring

Figure A-20: Displacer Connecting Rod

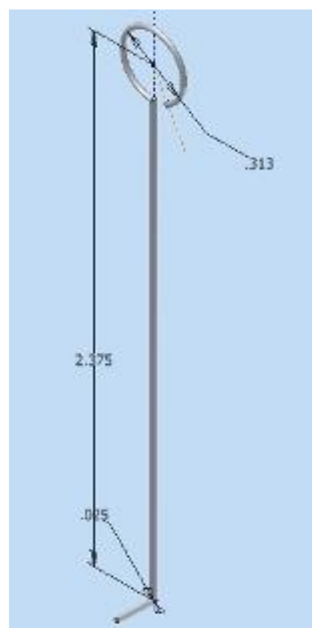

Figure A-21: Piston Connecting Rod

Prototype Views

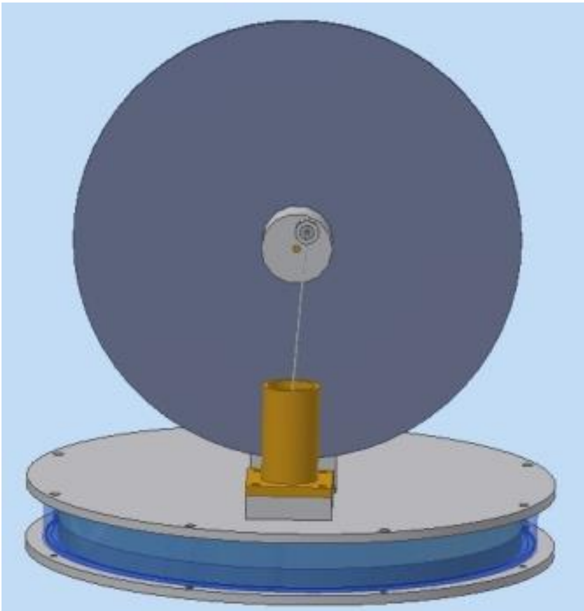

Figure A-22: Front view

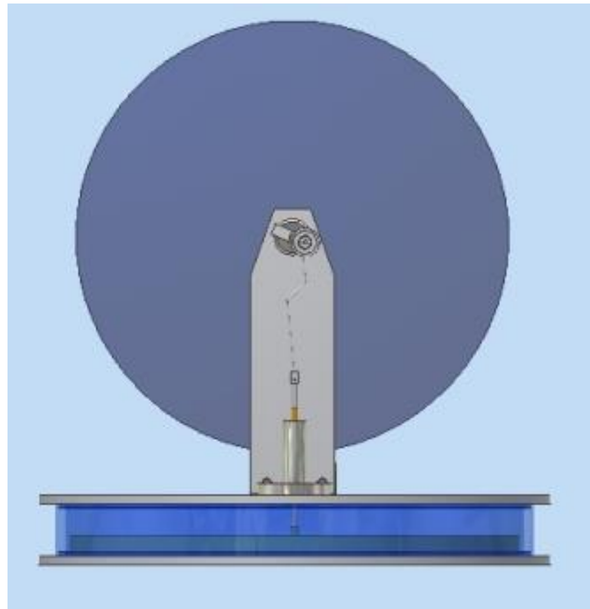

Figure A-23: Rare View

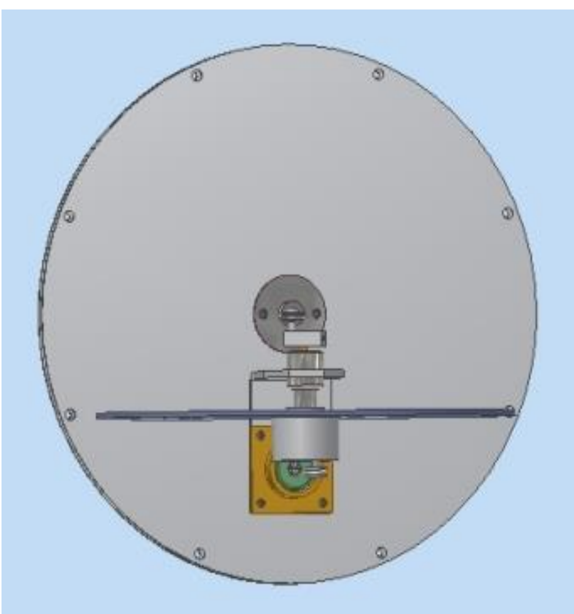

Figure A-24: Top View

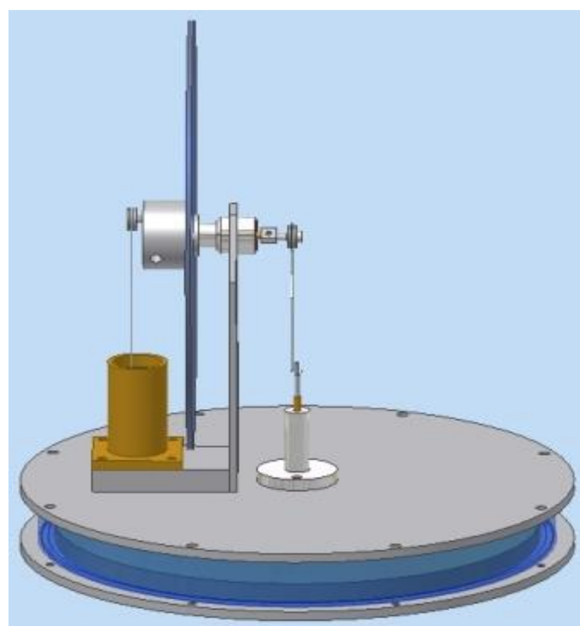

Figure A-25: Side View

References

1.Collie, M. J., ed. Stirling Engine Design and Feasibility for Automotive Use. New Jersey: Noyes Data Corporation, 1979

2.Gingery, David J. Build a Two Cylinder Stirling Cycle Engine. Springfield, MO: 1990.

3.Kolin, Ivo. Isothermal Stirling-Cycle Engine. University of Croatia: Zagreb Press, 1983.

4.Rizzo, James G. The Stirling Engine Manual. Somerset, Great Britain: Camden Miniature Steam Services, 1995.

5.Senft, James R. An Introduction to Low Temperature Differential Stirling Engines. River Falls, WI: Moriya Press, 1996.

6.Senft, James R. An Introduction to Stirling Engines. River Falls, WI: Moriya Press, 1993.

7.Walker G., Senft J. R., Free Piston Stirling Engines. Heidelberg, Germany: Mercedes-Druck, 1985.

8.West, C. D. Principles and applications of Stirling Engines. New York: Van Nostrand Reinhold Company, 1986.